Data Analysis, Determination of Detection Efficiency & Radiative Correction Calculation of R Measurement

Xiangrong Qi
Institute of High Energy Physics, Beijing 100039,P. R. China

October 26, 1999

1 Introduction

The lowest order cross section for $e^+e^- \to \gamma^* \to$hadrons is usually parameterized in terms of the ratio R, which is defined as followed,

$$R \equiv \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}, \tag{1}$$

where the denominator is the lowest-order QED cross section and equals $4\pi\alpha^2/3s$.

The ratio of R has been measured by many experiments over a large CM energy range from the hadron production threshold to the Z^0 mass [1]. Experimentally determined R values are, in general, consistent with theoretical predictions, and provide an impressive confirmation of the hypothesis of three color degrees of freedom for quarks.

The current values for R below 5 GeV have experimental uncertainties on the order of 15%[2, 3, 4, 5]. These uncertainties limit the precision of $\alpha(M_Z^2)$ and a_μ, in turn, the determination of the Higgs mass from radiative corrections in the standard model[6, 7, 8]. About 50% and 20% of the uncertainty in $\alpha(M_Z^2)$ and $a_\mu = (g-2)/2$, respectively, are due to the uncertainty of the values of R in the 2-5 GeV cm energy region [15].

The BES collaboration has started a program of R measurements over the 2-5 GeV energy range with the goal of reducing the present uncertainties by a factor of two or more. The measurements were carried out with the upgraded BES detector (BESII), which is a conventional solenoidal detector that is described in some detail in Ref. [11].

2 Experimental Measurement of R

A first scan of R measurements was performed in the spring of 1998 with data samples of at least 1500 hadronic events collected each at 2.6, 3.2, 3.4, 3.55, 4.6 and 5.0 GeV. To understand beam-associated backgrounds, separated beam data were taken at each energy point, and single beam data were accumulated at 3.55 GeV. Additionally, data were taken

at the J/ψ and ψ' resonances to provide a precise energy calibration as well as a cross check of the trigger efficiencies for the Bhabha, dimuon and hadronic events measured in the R scan. The 3.4 GeV point was remeasured after a time interval of about two weeks to test the stability of the detector.

The value of R is determined from the number of observed hadronic events (N_{had}^{obs}) by the relation

$$R = \frac{\sigma^0_{hadrons}}{\sigma^0_{\mu\mu}} = \frac{N_{had}^{obs} - N_{bg} - \sum_l N_{ll} - N_{\gamma\gamma}}{\sigma^0_{\mu\mu} \cdot \mathcal{L} \cdot \epsilon_{had} \cdot \epsilon_{trg} \cdot (1+\delta)} \tag{2}$$

where $\sigma^0_{\mu\mu}$ is the lowest order cross section of the μ pair process, N_{bg} is the number of beam associated background events; $\sum_l N_{ll}$, $(l = e, \mu, \tau)$ and $N_{\gamma\gamma}$ are the numbers of misidentified lepton-pair and two-photon processes events; $\mathcal{L}$ is the integrated luminosity; $1+\delta$ is the factor of initial state radiation; and ϵ_{had} and ϵ_{trg} represent the detection and trigger efficiencies for the hadronic events.

2.1 Hadronic Event Selection and Background subtraction

We begin our event selection with good track selection. dE/dx information, polar angle, energy, momentum and TOF cuts were used to identify a good track. After the track-level selection, a further event-level selection, based on the angle between tracks and their energy, was used to distinguish good events from cosmic rays and lepton pair events.

Charged track selection:

• geometry acceptance : $|\cos\theta| < 0.84$;

• a reasonable three-dimension helix fit (Mfit=2 or -19);

• good track in MDC : $N_{hits} > 16$ (Mfit=-19);

• vertex: $|v_{xy}|$ <2.0 cm, $|v_Z|$ <18 cm (Mfit=2);

• momentum : $p < p_{beam} + 5 \times \sigma_{p_{beam}}$;

• time-of-flight : $2 < t < t_p + 5\sigma$ (ns);

• energy : $E < 0.6E_{beam}$ or $E > 1.0GeV$;

• remove any electron track and track with muon signal.

Event level selection:

• At least two charged tracks, with at least one good track satisfying the requireemts listed above;

• The total deposited energy in BSC $\sum E_{sc} > 0.28 E_{beam}$;

• All the charged tracks not be positive($\geq$ 3pr).

For $N_{chrg} = 2$, addiational requirements :

• reject back-to-back events:

$$\mid \theta_1 + \theta_2 - 180^\circ \mid > 10^\circ;$$
$$\mid\mid \phi_1 - \phi_2 \mid - 180^\circ \mid > 4^\circ.$$

• at least 2 isolated neutral tracks :

$$E_\gamma > 100 MeV, \quad \mid \phi_\gamma - \phi_c \mid > 15^\circ.$$

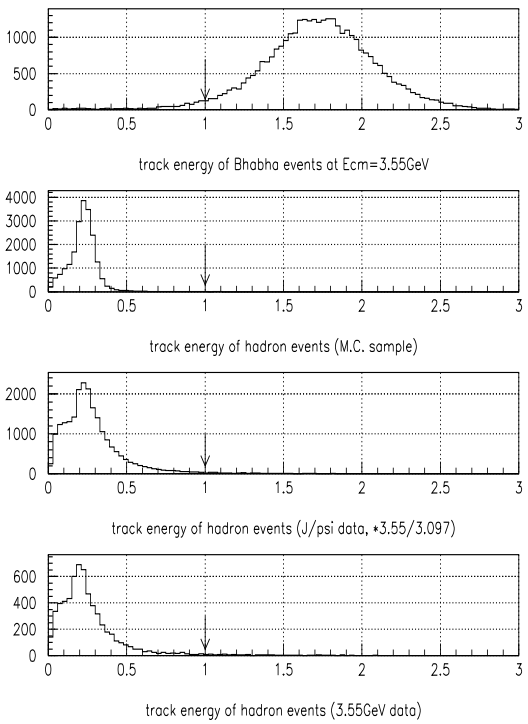


Figure 1: Track energy of Bhabha and hadron events

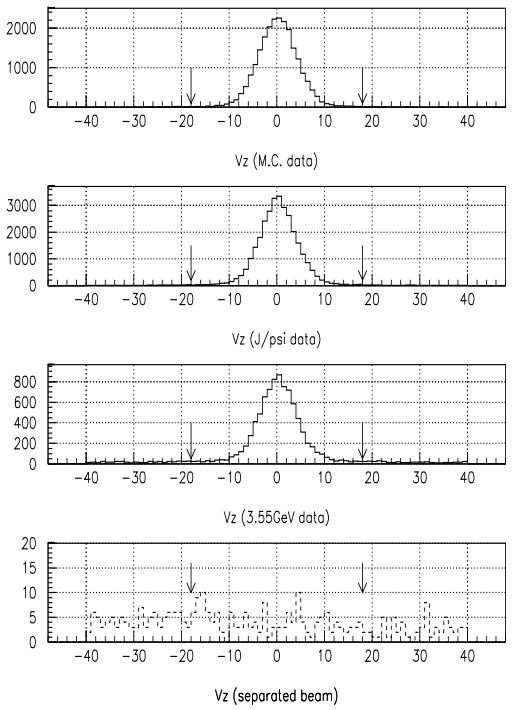


Figure 2: V_z cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data (tracks with MFIT=2)

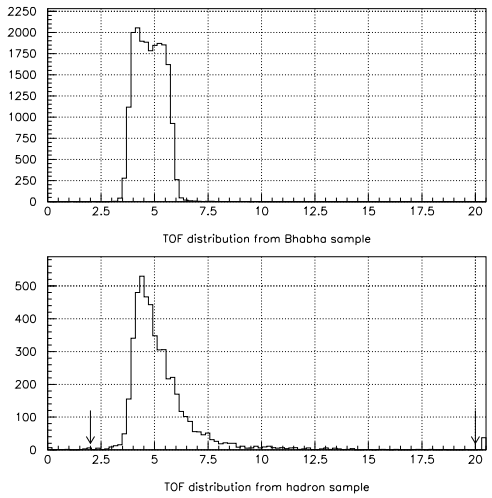


Figure 3: TOF cut at 3.4GeV

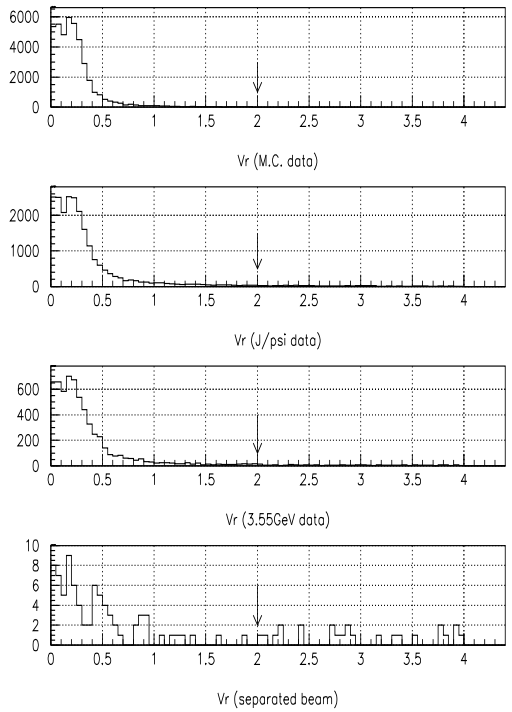


Figure 4: V_r cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data for tracks with MFIT=2

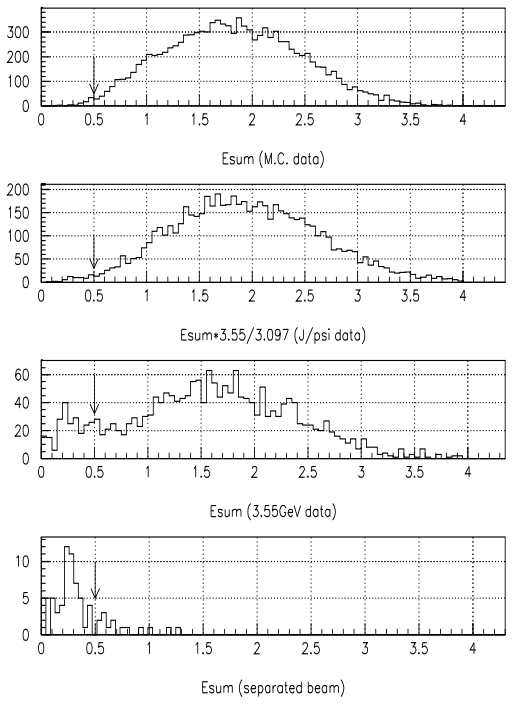


Figure 5: E_{sum} cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data

Tau pair production and residual two-photon processes, were subtracted out statistically via Monte Carlo simulation. Most beam associated background events were rejected by a vertex cut. The same hadronic event selection criteria were applied to the separated-beam data, and the number of the beam associated background events N_{bg} in the corresponding hadronic event sample was obtained as a function of the number of separated-beam events N_{sep}, the pressure P at the collision region, and the integrated beam current I.

The performance of the event selection routines were checked by event display, which were carried out for both the selected and rejected hadronic events, the separated-beam data, and the Monte Carlo events. We determined the error associated with the hadronic selection criteria from changes in the event yield caused by varying the selection requirements and from the results of the hand scan.

2.2 Hadronic Detection Efficiency

The integrated luminosity was determined using large-angle Bhabha events with selection criteria based on the energy and the angular distribution of two clusters in the BSC. A cross check using only MDC information (dE/dx) was generally consistent with the BSC measurement; the difference was taken into account in the systematic error.

The detection efficiency for hadronic events was determined via a Monte Carlo simulation using the JETSET7.4 event generator[12]. Parameters in the JETSET7.4 generator were tuned using more than 40,000 hadronic events selected from the tau mass measurement data sample[13]. The parameters of the generator were adjusted to reproduce distributions of kinematic variables such as multiplicity, sphericity, transverse momentum, etc. Figure 9 shows the charge multiplicity, the sphericity, the aplanarity and the transverse momentum distributions for the real and simulated event samples.

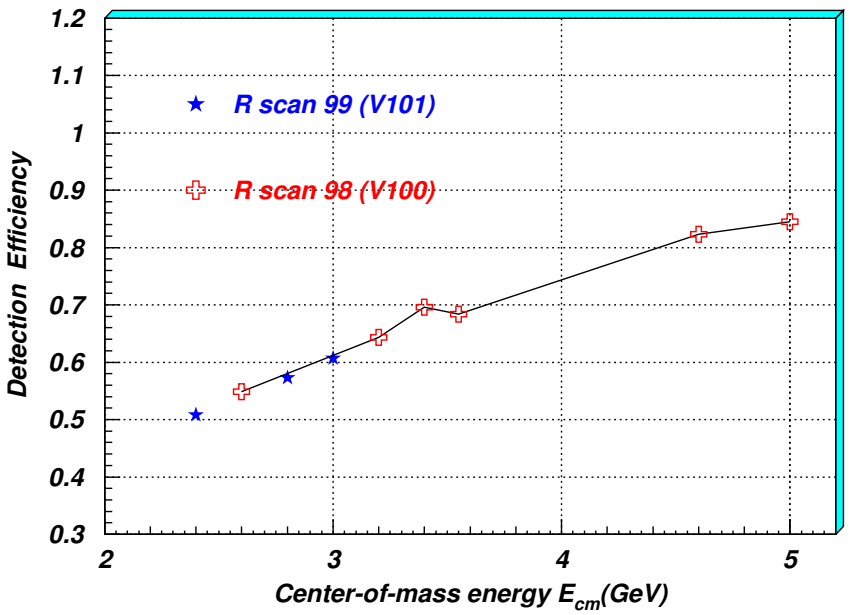


Figure 6: Detection efficiecny at six energy points of first R scan

2.3 Initial State Radiation Correction

The effect of the higher order electromagnetic processes, whose contributions are represented by radiative correction factor $1 + \delta$, should be removed from the measured cross-section. Four different schemes were examined: Berends and Kleiss[14], Kuraev and Fadin[15], Bonneau and Martin[16], and a method used by the Crystal Ball[17]. Radiative corrections calculated by all these methods were consistent within $1 \sim 2\%$ for off-resonance points.

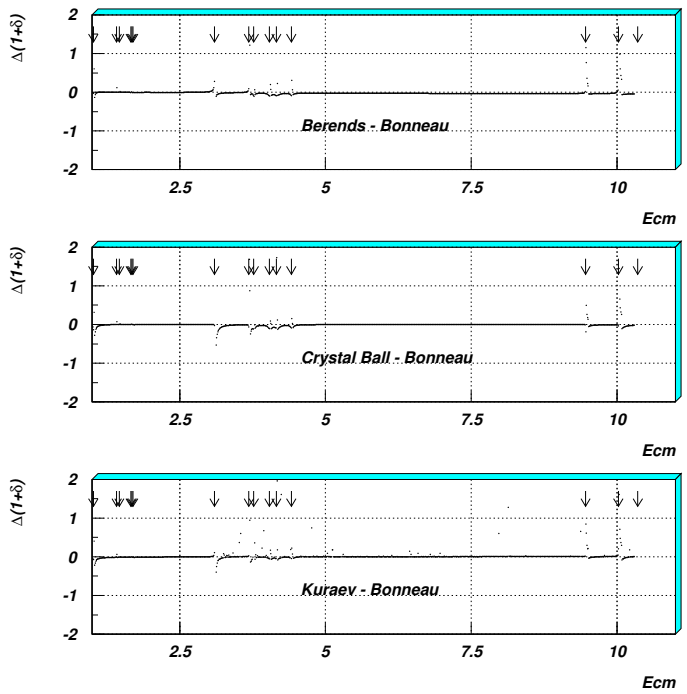


Figure 7: Radiative correction with different scheme

We used the approach of Bonneau and Martin, with the differences from the other schemes included in the systematic error.

2.4 Preliminary Results and Future Plans

The preliminary R values obtained at the six energy points are shown in Table 1 and graphically displayed in Figure 10. A further breakdown of contributions to the systematic errors is given in Table 2. In 1999, BESII will carry out a finer scan from 2 to 5 GeV. Our goal is to reduce the present uncertainties of R by at least a factor of two over this entire energy region.

References

[1] Particle Data Group, Eur. Phys. J. **C3** 204 (1998).

[2] F. Ceradini et al., Phys. Lett. **B47** (1973) 80;
B. Batoli et al., Phys. Rev. **D6** (1972) 2374;
M. Bernardini et al., Phys. Lett. **B51** (1974) 200.

[3] G. Cosme et al., Phys. Lett. **B40** (1972) 685.

[4] M. Kurdadze et al., Phys. Lett. **B42** (1972) 515.

[5] A. Litke et al., Phys. Rev. Lett. **30** (1973) 1189.

[6] A. Blondel, plenary talk at ICHEP'96, Warsaw.

[7] B. Pietrzyk, Rad. Corr. Conf., Cracow 1996.

[8] M. Davier and A. Hoeker, LAL 97-85.

[9] M. Davier and A. Hoeker, LAL 97-02.

[10] H. Burkhardt and B. Pietrzyk, Phys. Lett. **B356** (1995) 398.

[11] J.Z. Bai et al., Nucl. Instr. and Methods in Phys. Research **A344** (1994) 319.

[12] Torbjoen Sjoestrand, LU TP 95-20.

[13] X.R. Qi et al., High Energy Physics and Nuclear Physics (in Chinese), **23**,1,(1999).

[14] F.A. Berends and R. Kleiss, Nucl. Phys. **B178** (1981) 141.

[15] E. A. Kuraev and V. S. Fadin, Sov. J. Nucl. Phys. **41** (3) (1985) 3.

[16] G. Bonneau and F. Martin, Nucl. Phys. **B27** (1971) 387.

[17] C. Edwards et al., SLAC-PUB 5160 (1990)

Table 1: Summary of R data and values.

E_{cm}	N_{had}^{obs}	N_{bg}	$\mathcal{L}$ (nb^{-1})	$\epsilon_{had}(\%)$	$(1+\delta)$	$\sigma^0_{\mu\mu}$	R value	Syst. err.	Stat. err.
2.60	5617	8	292.9	0.5482	1.009	12.840	2.61	6.59%	1.36%
3.20	2051	10	109.3	0.6430	1.447	8.477	2.25	5.65%	2.27%
3.40	2149	46	135.3	0.6961	1.173	7.509	2.36	6.80%	2.26%
3.55	2672	50	200.2	0.6840	1.125	6.888	2.29	7.17%	2.03%
4.60	1497	48	87.7	0.8227	1.079	4.102	3.53	8.93%	2.98%
5.00	1648	26	102.3	0.8453	1.068	3.472	3.42	10.27%	3.02%

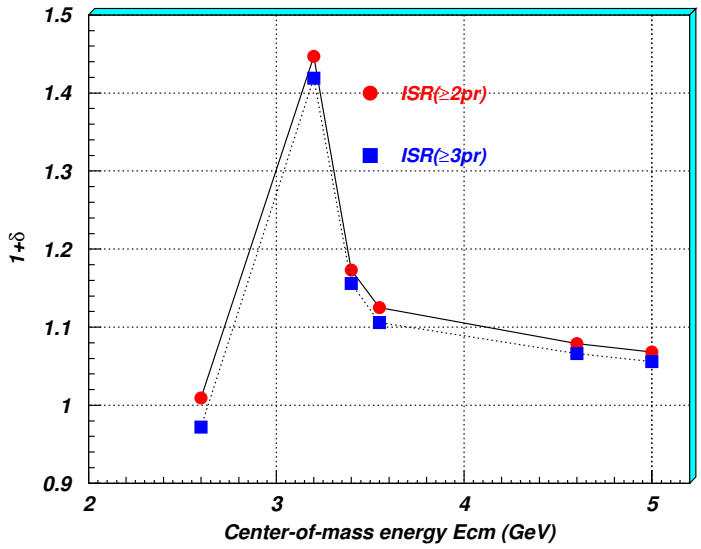
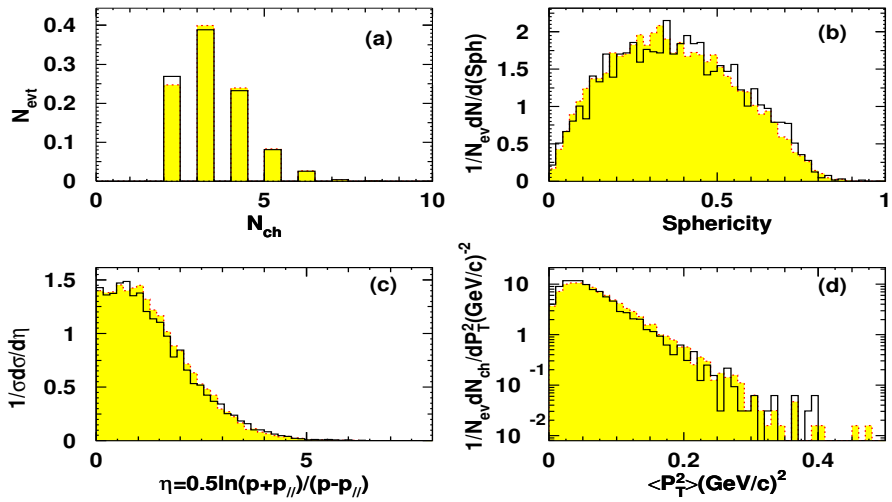


Figure 8: Radiative correction at six energy points of first R scan



): Comparison of hadronic event shapes between data (shaded region) a
istogram). (a) Multiplicity; (b) Sphericity; (c) Rapidity; (d) Transverse m

Figure 9: Comparison of hadronic event shapes between data (shaded region) and Monte Carlo (histogram). (a) Multiplicity; (b) Sphericity; (c) Rapidity; (d) Transverse momentum.

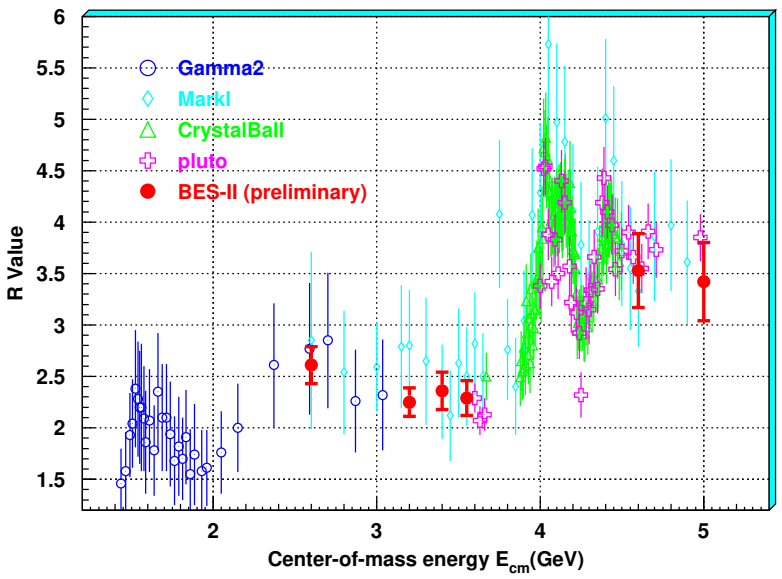


Figure 10: Plot of R values at the 6 data points vs E_{cm}.

Figure 10: Plot of R values at the 6 data points vs E_{cm}.

Table 2: Contributions to systematic errors. All errors are in percentages (%).

E_{cm}	Had. select	Background	$\mathcal{L}$	τ-pair	Bhabhas	ϵ_{had}	Trigger	Rad. corr
2.60	5.25	0.06	2.12	0.00	0.04	2.60	0.50	2.58
3.20	4.03	0.15	2.83	0.00	0.04	1.90	0.50	2.17
3.40	5.06	0.27	2.83	0.00	0.04	2.90	0.50	3.02
3.55	6.05	0.27	2.32	0.00	0.04	2.30	0.50	2.35
4.60	7.58	0.75	2.16	0.32	0.00	3.60	0.50	4.13
5.00	9.00	1.26	2.81	0.32	0.00	3.20	0.50	3.82